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Endoscopic Lithotripsy With the Holmium:YAG Laser

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Background and Objective: **The holmium:YAG (Ho:YAG) laser can be used not only for soft tissue but also for hard tissue such as urinary calculi. The objective of this study was to assess the usefulness of the Ho:YAG laser for endoscopic lithotripsy in patients with urinary tract stone.**
Study Design/Materials and Methods: **Of 102 procedures performed among 96 patients, 88 were transurethral ureterolithotripsy (TUL), seven were percutaneous nephrolithotripsy, and seven were transurethral cystolithotripsy. Six patients had bilateral stones. The fragments were reduced as much as possible with the Ho:YAG laser.**
Results: **The efficacy rate of the 102 lithotripsy procedures was 93%. With respect to the effect of TUL, the efficacy rates of 40 procedures for the proximal ureter, 18 procedures for the midureter, and 30 procedures for the distal ureter were 85%, 94%, and 100%, respectively.**
Conclusion: **The Ho:YAG laser produced a sufficiently strong lithotripsy force on all stones. The results of this study indicate that lithotripsy of urinary tract stones with the Ho:YAG laser can achieve a clinical outcome equivalent to or exceeding that of pulsed dye laser lithotripsy. The Ho:YAG laser is a multipurpose laser and thus is a cost effective and very useful means for endoscopic lithotripsy of urinary tract stones. Lasers Surg. Med. 25:389–395, 1999.**

Key words: endoscopy; holmium:YAG; laser lithotripsy; urinary tract stone

INTRODUCTION

The holmium:YAG (Ho:YAG) laser is a multipurpose laser that is applicable not only to soft tissue [1–7] but also to hard tissue such as urinary tract stone [8–12]. In the treatment of urinary tract stone, the Ho:YAG wavelength can efficiently fragment cystine calculi, for which a conventional pulsed dye laser is not effective. Moreover, lithotripsy with this laser produces smaller fragments than does lithoclast, pulsed dye laser, or electrohydraulic lithotripsy [13]. It is not necessary to remove stone fragments with a basket catheter. We previously reported on preliminary data of endoscopic Ho:YAG laser lithotripsy in a small number of patients [9]. The present study evaluated the clinical usefulness of the Ho:YAG laser in the treatment of a much larger number of patients with urinary tract stone.

PATIENTS AND METHODS

The subjects of the study were 96 patients undergoing endoscopic lithotripsy of urinary tract stones with a Ho:YAG laser. These patients consisted of 52 men and 44 women whose ages ranged from 14 to 85 years. The 96 patients, six of

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whom had bilateral stones, underwent a total of 102 endoscopic lithotripsy procedures consisting of 88 transurethral ureterolithotripsies (TULs), seven percutaneous nephroureterolithotripsies (PNLs), and seven transurethral vesicolithotripsies. All of the endoscopic manipulations were conducted under epidural anesthesia. To perform safe and precise operative manipulations, radioscopy and a video monitor were used.

In performing TUL, a semirigid ureteroscope was used mainly for stones in the middle and distal ureter in men and in the proximal, middle, and distal ureter in women. A flexible ureterorenoscope was used for renal stones in both men and women and for stones in the proximal ureter in men. A rigid renoscope was used to perform PNL, and a 24 F panendoscope (Karl Storz, Tuttlingen) was used to perform transurethral vesicolithotripsy.

By using physiological saline as a perfusate, we performed all endoscopic procedures under video monitoring. For TUL, a semirigid ureteroscope was introduced directly into the ureter without a guidewire or dilating the ureteral orifice. The ureteroscope was then advanced immediately beneath the stone to bring the tip of a laser fiber into contact with the stone surface, followed by lithotripsy. When a flexible ureteroscope was used, a guidewire was introduced directly underneath the stone, and then a flexible ureteroscope was advanced into the ureter along the guidewire. At that time, the ureteral orifice was dilated only when required. When the flexible ureteroscope was inserted at the proper position, the guidewire was removed. No safety wire was inserted during lithotripsy. For PNL, an ultrasound-guided puncture was made on the calyx, and the nephrostomy was dilated along a guidewire, followed by lithotripsy with a laser fiber, which was passed through a 6-F ureteral catheter using a 26-F rigid renoscope. For bladder stones, lithotripsy was performed through a laser fiber that was passed through a 6-F ureteral catheter in a working channel of a 24-F panendoscope.

The laser generator used was a VersaPulse Select (Coherent, Palo Alto, CA). A bare fiber 365 μm in diameter was used in the present series, but a bare fiber 200 μm in diameter has been used recently in performing TUL. The laser radiation conditions at the time of TUL, PNL, and vesicolithotripsy included a 0.5–1.0 J/pulse or 5–10 pulses/sec. However, depending on the patient, 1.2 J/pulse or 15 pulses/sec were used, although rarely. In the initial 20 cases, to fragment the stone by TUL, a hole was bored into the center of the stone at low output by using a drilling effect, and a laser fiber was passed through the hole to break the stone at high output. However, in the 21st and subsequent cases, piecemeal lithotripsy was performed, starting from the peripheral stone. For impact stones, however, the center was lithotripsied first to fragment the stone into two or three small pieces, which were then pulverized further into smaller pieces. In performing lithotripsy, the lithotripsied fragments were reduced to the smallest possible size. The criterion for terminating laser lithotripsy was the time point at which all of the lithotripsied fragments were ≤2 mm and sufficient spontaneous excretion could be expected. If the lithotripsied fragments measured ≥3 mm and renal migration was detected, laser lithotripsy was resumed by replacing the rigid ureteroscope with a flexible ureteroscope. If the lithotripsied stones migrating into the kidney were >3 mm and were refractory to laser lithotripsy when using a flexible ureteroscope, extracorporeal shock wave lithotripsy (ESWL) was performed to bring about smooth excretion of the stones.

After termination of laser lithotripsy, only one fragment was collected for compositional analysis; removal using a basket catheter was not performed for any of the remaining stones. A double-J stent was inserted for 3–5 days after laser lithotripsy in all patients. For PNL, laser lithotripsy was continued until the entire stone was removed under a rigid renoscope. For bladder stones, laser lithotripsy was continued similarly until complete endoscopic removal of the stone was achieved.

In evaluating the efficacy of treatment, the direct effect was assessed 1–2 days after laser lithotripsy by plain film of the kidney–ureter–bladder (KUB) and the final effect at 6 weeks by KUB and intravenous pyelography. In other words, with respect to the direct effect, the presence of no stones or of stones ≤4 mm, if any, permitting spontaneous stone excretion, was evaluated as effective and the presence of residual stones measuring ≥5 mm as ineffective. At 6 weeks, the presence of no stones was evaluated as markedly effective and the presence of residual stones measuring <4 mm as effective. Results were evaluated as ineffective if residual stones of ≥5 mm were present. Even after 6 weeks, follow-up observation was continued for as long as pos-

TABLE 1. Composition of Stone Fragments

Calcium oxalate + calcium phosphate	43
Calcium oxalate monohydrate	18
Calcium phosphate	5
Magnecium ammonium phosphate	3
Cystine	1
Uric acid	1

sible to determine the presence or absence of any effect of laser lithotripsy on the urinary tract system and recurrent stones.

RESULTS

Components of Stones

Compositional analysis was conducted on stones obtained from 71 of the 102 endoscopic lithotripsy procedures. As shown in Table 1, a stone composed of cystine and uric acid was found in only one case. All stones permitted lithotripsy with the Ho:YAG laser.

Stone Size and Radiation Energy (Table 2)

Patients who underwent TUL had a mean stone size of 11 mm (longest diameter: range = 5–22 mm) × 6 mm (shortest diameter: range = 2–12 mm), and a mean radiation energy of 1.8 J (range = 0.06–15 J) was required. In the PNL patients, the mean stone size was 23 mm (longest diameter: range = 18–30 mm) × 16 mm (shortest diameter: range = 11–20 mm), and a mean radiation energy of 2.7 J (range = 0.44–6.3 J) was required. In those who underwent vesicolithotripsy, the mean stone size was 19 mm (longest diameter: range = 18–20 mm) × 11 mm (shortest diameter: range = 9–15 mm), and the mean radiation energy required was 4.6 J (range = 1.6–9.0 J).

Direct Effect (Tables 3, 4)

The efficacy of all 102 lithotripsy procedures using the Ho:YAG laser was assessed 1–2 days after the lithotripsy by KUB. Fifty-nine procedures resulted in the total elimination of stones; 34 resulted in residual stones measuring <4 mm, thus permitting spontaneous excretion; and nine resulted in residual stones measuring ≥5 mm. Of the 88 TUL procedures, 46 succeeded in totally eliminating stones and 33 left residual stones measuring <4 mm, for an efficacy rate of 90%. In nine procedures, there were residual stones measuring ≥5 mm.

Of 7 PNL procedures, six achieved total stone elimination and the remaining procedure left residual stones of <4 mm, thereby permitting elimination by spontaneous excretion.

All 7 vesicolithotripsy procedures resulted in the elimination of stones.

Of the TULs for the proximal ureter, 10 procedures resulted in total stone elimination and 24 resulted in residual stones measuring <4 mm (efficacy rate, 85%), but six resulted in residual stones of ≥5 mm. Of the TULs conducted for the midureter, the stone was eliminated by 12 procedures, and there were residual stones <4 mm in three procedures (efficacy rate, 83%). Three procedures resulted in residual stones of ≥5 mm. Of the TULs conducted for the distal ureter, stone elimination was achieved by 24 procedures, and residual stones <4 mm were observed in six procedures (efficacy rate, 100%). No residual stones measuring ≥5 mm were observed.

TABLE 2. Stone Size and Total Energy Dose

Stone in	Mean size (mm)	Energy dose (kJ)
Kidney	23 × 16	2.7
Ureter	11 × 6	1.8
Bladder	19 × 11	4.6

TABLE 3. Clinical Results of Holmium:YAG Laser Lithotripsy*

	1–2 days posttreatment		6 weeks posttreatment	
Outcome	No. of procedures	%	No. of procedures	%
T + P + V				
Stone free	59	58	90	88
RS ≤4 mm	34	33	5	5
RS ≥5 mm	9	9	7	7
Total	102	Total	102	
TUL				
Stone free	46	52	76	86
RS ≤4 mm	33	38	5	6
RS ≥5 mm	9	10	7	8
Total	88	Total	88	
PNL				
Stone free	6	86	7	100
RS ≤4 mm	1	14	0	0
RS ≥5 mm	0	0	0	0
Total	7	Total	7	
V				
Stone free	7	100	7	100
RS ≤4 mm	0	0	0	0
RS ≥5 mm	0	0	0	0
Total	7	Total	7	

*T, TUL, transurethral ureterolithotripsy; P, PNL, percutaneous nephroureterolithotripsy; V; vesicolithotripsy; RS, residual stone.

TABLE 4. Clinical Results of Holmium:YAG Laser Ureterolithotripsy

	1–2 days posttreatment		6 weeks posttreatment	
Outcome	No. of procedures	%	No. of procedures	%
Proximal ureter				
Stone free	10	25	32	80
RS[a] ≤4 mm	24	60	2	5
RS ≥5 mm	6	15	6	15
Total	40	Total	40	
Midureter				
Stone free	12	66	16	88
RS ≤4 mm	3	17	1	6
RS ≥5 mm	3	17	1	6
Total	18	Total	18	
Distal ureter				
Stone free	24	80	28	93
RS ≤4 mm	6	20	2	7
RS ≥5 mm	0	0	0	0
Total	30	Total	30	

[a]RS, residual stone.

Final Effects (Tables 3, 4)

Assessment of the final effects of laser lithotripsy at the sixth postoperative week showed that, of the 102 procedures, 90 (88%) resulted in total stone elimination, five (5%) resulted in residual stones measuring < 4 mm, thereby permitting sufficient spontaneous excretion, and seven (7%) resulted in residual stones of ≥5 mm or was supplemented with subsequent ESWL. With respect to the final effects of TUL, of the 88 procedures, 76 (86%) resulted in total stone elimination, five (6%) resulted in residual stones <4 mm, and seven (8%) resulted in residual stones of ≥5 mm or was supplemented with subsequent ESWL. Of the 40 procedures for the proximal ureter, stone elimination was achieved in 32 (80%) cases, and there were residual stones <4 mm in two (5%) cases and residual stones ≥5 mm or subsequent ESWL in six (15%) cases. Of the 18 procedures for the midureter, stone elimination occurred in 16 (88%) cases, and there were residual stones <4 mm in one (6%) case and residual stones ≥5 mm or subsequent ESWL in another one (6%) case. Of the 30 procedures for the distal ureter, 28 (93%) induced stone elimination, and there were residual stones <4 mm in two (7%).

Complications

Perforations of the ureteral wall occurred in three patients during laser lithotripsy. Two of these occurred in case 5 (proximal ureter) and case 11 (distal ureter). Those two patients were among the initial 20 cases of laser lithotripsy using an Ho:YAG laser. The perforations occurred because of direct contact of the laser fiber with the ureteral wall when drilling a hole in the center of the stone. The third patient (case 59) had an impacted stone lodged in the midureter, which is refractory to lithotripsy. In this case, the perforation may have occurred because of contact of the tip of the laser fiber with the ureteral mucosa. In all three patients, the perforation healed uneventfully with installation of a ureteral stent for 1–2 weeks after lithotripsy, without developing ureteral stenosis or obliteration. Follow-up observation was conducted over 2 years and 6 months for case 5, 6 months for case 11, and 3 months for case 59, and no findings suggesting stenosis were identified on pyelography.

No other complications associated with endoscopic laser lithotripsy were observed.

Observation of the Postoperative Course

After assessing the final effects, follow-up observation was conducted over a mean period of 8.7 months (range = 2–36 months) in 75 patients, excluding drop-outs. Recurrence occurred in seven (9.3%) of the 75 patients. The mean period until relapse was 14 months (range = 5–29 months). No ureteral obliterations, including ureteral stenosis, were found during the postoperative follow-up period.

DISCUSSION

Compositional analysis was conducted on the stones collected during the 71 lithotripsy procedures. One stone consisted of cystine and another of uric acid, but they were lithotripsied without difficulty during the procedure. In particular, cystine stones are refractory to lithotripsy with a pulsed dye laser. This demonstrated the superiority of the Ho:YAG laser over the pulsed dye laser. The pulsed dye laser has a wavelength of 504 nm that is selectively absorbed by black or brown, which is the color of many urinary tract stones. Therefore, it is ineffective for so-called pale stones such as a cystine stone [14,15]. Conversely, the Ho:YAG laser has a wavelength of 2,100 nm, which can be absorbed to a large extent by water; hence, the laser beam can be absorbed by water present in the micropores on the stone surface, producing an effect irrespective of the color of the stone.

The mechanism by which lithotripsy is accomplished by the pulsed dye laser is that the

surface of the stone irradiated with the laser beam is ionized to form plasma, which in turn serves as an absorber of the laser beam to generate cavitation bubbles whose abrupt expansion produces a pressure wave that pulverizes the stone [16]. With the Ho:YAG laser, the laser beam is absorbed directly by water [17] present on the surface of the stone, and cavitation bubbles are formed in the water, thereby producing a pressure wave that pulverizes the stone. As such, both the pulsed dye laser and the Ho:YAG laser achieve lithotripsy by generating cavitation bubbles, but the pulverization produced by the two lasers is markedly different. Whereas the pulsed dye laser causes lithotripsy by cracking the stone through a splitting action, the Ho:YAG laser causes lithotripsy by fragmenting the stone through a shaving action, thereby pulverizing the stone piecemeal from its surface. These facts have been documented in a recent report [13]. More specifically, stone pieces lithotripsied with four kinds of lithotriptors, including an electrohydraulic lithotriptor, a mechanical lithotriptor, a pulsed dye laser, and a Ho:YAG laser, were analyzed for calcium phosphate, calcium oxalate monohydrate, cystine, magnesium ammonium phosphate, and uric acid. Of the four lithotriptors, the Ho:YAG laser produced the smallest lithotripsied fragments among all types of stone components [13].

In lithotripsy using the Ho:YAG laser, the energy was set at 0.5–1.0 J/pulse or 5–10 pulses/sec, but in most patients, 0.5 J/pulse or 5 pulses/sec at 2.5 W were used because these conditions were reported by Bagley and Erhard [18] as the basic output and produced adequate force. As the effect on the stone is seen, the parameters can be altered as necessary. Higher energy settings may be necessary for harder stones, whereas higher frequencies may increase movement of the calculus. When the stones are large or cannot be pushed up, laser irradiation is sometimes started at 0.8 J/pulse and 8 pulses/sec or at 1.0 J/pulse and 8 pulses/sec to reduce the time of treatment. For example, large and impacted ureteral stones may be first irradiated at 1.0 J/pulse and 10 pulses/sec, and remaining stone fragments >5 mm are further fragmented at 0.5 J/pulse and 5 pulses/sec for the prevention of pushing up. In contrast, lithotripsy may be started at 0.5 J/pulse and 5 pulses/sec with joules or pulses being gradually increased when the stones are difficult to destroy. In PNL for renal calculus or vesicolithotripsy for bladder stone, it is possible to increase the power setting according to the size of the stones because of the safety in the destruction of stones due to a wide view of endoscopic operation. In the present report, we used a maximal energy of only 1.2 J/pulse and a pulse rate of up to 15 pulses, but we have recently used a power setting as high as 2.0 J/pulse and 20 pulses/sec for large stones of approximately 3–5 cm. Such a power setting considerably reduces the time of surgery. However, this setting requires a generator for high-output laser with a maximal output of 60 W. We used three laser generators issuing a maximal output of 22 W, 60 W, and 80 W, respectively, but laser generators outputting 22 W and 60 W are sufficient for lithotripsy. The highest output laser generator is effective for resection of soft tissues, particularly in prostatectomy [1,3,19,20].

To use the Ho:YAG laser for urothelial tumor ablation, the fiber is placed near or on the tissue to be removed. The laser is set at 0.8–1.2 J with a frequency of 8–12 Hz and activated. For incisions, ureteral strictures, and ureteropelvic junction obstruction, the fiber should be in contact with the tissue. The Ho:YAG laser has been used at energies of 1–1.5 J with frequencies of 12–15 Hz or more.

In assessing the effects of lithotripsy, the evaluation was divided into direct effect (1–2 days after lithotripsy) and final effect (6 weeks postprocedure) for determining the state of stone excretion. Because we decided to wait for spontaneous stone excretion in the urine stream without stone removal using a basket catheter or stone forceps for small residual stones, evaluation of the direct effect was helpful for predicting future spontaneous stone excretion. In evaluating the direct effect, the size of the residual stones was sometimes overestimated because small stones were overlapping because of the condition of the residual stones, but, overall, there was no substantial difference between the direct and final effects.

In the case of PNL and vesicolithotripsy, because the stones are removed from the body after lithotripsy, it is better not to consider those procedures as equivalent to TUL when evaluating the final effect. However, from the aspect of efficacy of lithotripsy by Ho:YAG laser, lithotripsy was achieved in all 102 (100%) lithotripsy procedures, which included PNL and vesicolithotripsy. Conversely, the pulsed dye laser had an efficacy rate of 78–98% for lithotripsy [14,15,21,22]. The final effect in our patients treated by TUL using the Ho:YAG laser was 92% efficacy. However, the results of pulsed dye laser included litholapaxy

with a basket catheter after lithotripsy in 13–80% of patients. Considering this fact, the present result using Ho:YAG laser lithotripsy with the expectation of spontaneous postlithotripsy stone excretion was better. In other reports of lithotripsy using the Ho:YAG laser, efficacy has been cited as 87–95% [9,10,23,24], similar to the that in the present report. However, we did not perform litholapaxy after lithotripsy in any patient. ESWL was applied actively for residual stones measuring ≥3 mm to accelerate their spontaneous excretion. Therefore, the actual efficacy rate was considered even better.

Differences in the results by stone location in the case of TUL may be caused by the difference in the distance to the stones rather than by the capability of the laser fragmenting the stones. A shorter distance to the stones tends to produce better results and a longer distance poorer results. A shorter distance allows an easier endoscopic operation and reliable laser irradiation of the stones.

We conventionally used a double-J stent in all patients after lithotripsy but will not use it in the future because it is not necessary except for cases of ureteral perforation or for cases of large stones in the proximal ureter after a prolonged operation.

In the case of low calyx stones, a 365-μm laser fiber could not produce sufficient bending of the flexible ureterorenoscope, which hindered lithotripsy. This problem was resolved by using a 200-μm fiber. The 200-μm fiber has rich flexibility, and bending of the flexible ureterorenoscope was not hindered.

Although ureteral perforation was encountered, injury to the ureteral wall by the use of Ho:YAG laser can be expected if the laser is not administered correctly because it can also be applied to soft tissues. We experienced three cases of ureteral perforation, which was detected by perioperative radiography. In performing lithotripsy for urinary calculus, we always infuse a contrast medium several times and confirm the absence of ureteral perforation. The initial two complications were due to the procedural inexperience of the technician, and the remaining case, which occurred in a patient with impacted stones refractory to lithotripsy, was due to continuing lithotripsy despite poor perfusion and visual conditions. When the Ho:YAG laser is used, it is important to visually identify the tip of the laser fiber. To achieve this, the laser must be irradiated while confirming the flow of the perfusate and the positional relation between the stone and the ureteral wall. Ensuring these conditions will avoid injuries to the ureteral wall with the Ho:YAG laser. Other reports have demonstrated a low rate of complications with the Ho:YAG laser because of the shallow depth of tissue penetration [10,23,25].

Postoperatively, we administer antibiotics to all patients to prevent infection; to date, no cases have developed sepsis.

In conclusion, the Ho:YAG laser produced a sufficiently strong lithotripsy force on all of the stones and was safe provided that the laser fiber did not come into direct contact with the ureteral mucosa during the lithotripsy procedure. The present results indicate that lithotripsy of urinary tract stones with a Ho:YAG laser can achieve a clinical outcome equivalent to or exceeding that of pulsed dye laser lithotripsy and, accordingly, can serve as a very useful means for endoscopic lithotripsy of urinary tract stones.

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